

# DISCOVERY OF METEORITIC BAGHDADITE, $\text{Ca}_3(\text{Zr,Ti})\text{Si}_2\text{O}_9$ , IN ALLENDE: THE FIRST SOLAR SILICATE WITH STRUCTURALLY ESSENTIAL ZIRCONIUM?

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**Introduction:** During an ongoing nanomineralogy investigation of the Allende CV3 carbonaceous chondrite, baghdadite,  $\text{Ca}_3(\text{Zr,Ti})\text{Si}_2\text{O}_9$ , has been identified in a V-rich, fluffy Type A Ca-Al-rich refractory inclusion (CAI), *A-WPI*, in USNM 7617. Reported here is the first meteoritic occurrence of baghdadite, as an ultra-refractory silicate mineral in a CAI from a primitive meteorite, among the first solid materials formed in the solar system. Field-emission scanning electron microscope (SEM), energy-dispersive X-ray spectroscopy (EDS), electron back-scatter diffraction (EBSD) and electron probe microanalyzer (EPMA) were used to characterize baghdadite and associated phases. Three new minerals burnettite (IMA 2013-054;  $\text{CaV}^{3+}\text{AlSiO}_6$ ), paqueite (IMA 2013-053;  $\text{Ca}_3\text{TiSi}_2(\text{Al}_2\text{Ti})\text{O}_{14}$ ) and beckettite (IMA 2015-001;  $\text{Ca}_2\text{V}^{3+}_6\text{Al}_6\text{O}_{20}$ ), were also discovered in *A-WPI* [1-4].

**Occurrence, Chemistry, and Crystallography:** Baghdadite occurs as one euhedral grain, 0.8  $\mu\text{m}$  in size, within aluminous melilite in *A-WPI* (Fig. 1). The V-rich Type A CAI (0.6  $\times$  1 mm in size) also contain primary spinel, perovskite, paqueite, burnettite, grossmanite-davisite, hibonite, and refractory metal grains in melilite [3]. The CAI is highly altered, containing secondary grossular, anorthite, coulsonite, hercynite, corundum, and beckettite [4].

The chemical composition of baghdadite by low-voltage SEM-EDS is (wt%) CaO 40.02,  $\text{SiO}_2$  29.29,  $\text{ZrO}_2$  17.41,  $\text{TiO}_2$  7.24,  $\text{Al}_2\text{O}_3$  4.56, MgO 0.84,  $\text{Nb}_2\text{O}_5$  0.63, sum 100.00, showing an empirical formula of  $(\text{Ca}_{2.77}\text{Mg}_{0.08})(\text{Zr}_{0.55}\text{Ti}_{0.35}\text{Nb}_{0.02})(\text{Si}_{1.89}\text{Al}_{0.35})\text{O}_9$ . The composition is slightly contaminated by host melilite due to its small size. The simplified formula is  $\text{Ca}_3(\text{Zr,Ti})\text{Si}_2\text{O}_9$ . EBSD analysis reveals that this Zr-rich silicate is baghdadite with a  $P2_1/a$  monoclinic structure.

**Origin and Significance:** Baghdadite is an ultra-refractory silicate, joining other Zr-rich refractory oxide minerals from carbonaceous chondrites including allendeite, tazheranite, lakargiite, zirconolite, kangite, panguite, zir-kelite, and baddeleyite. Baghdadite is probably the first solar silicate with structurally essential Zr, condensed from solar nebula gas or crystallized from a refractory melt.

**References:** [1] Ma C. 2013. *Mineralogical Magazine* 77:3002. [2] Ma C. et al. 2015. *Mineralogical Magazine* 79:531. [3] Ma C. and Beckett J.R. 2016. *LPSC* 47:A1595. [4] Ma C. et al. 2016. *LPSC* 47:A1704.

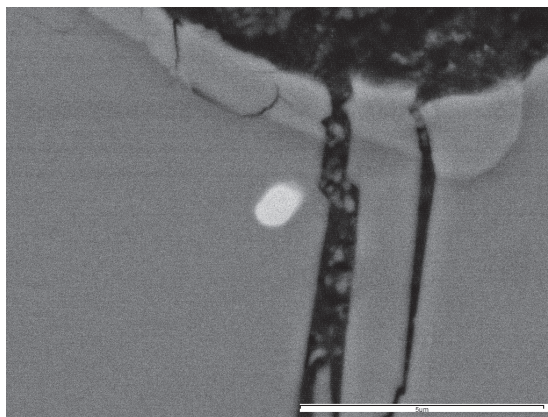


Fig. 1. Back-scatter electron image showing baghdadite (white phase) within melilite in the Allende CAI *A-WPI*.